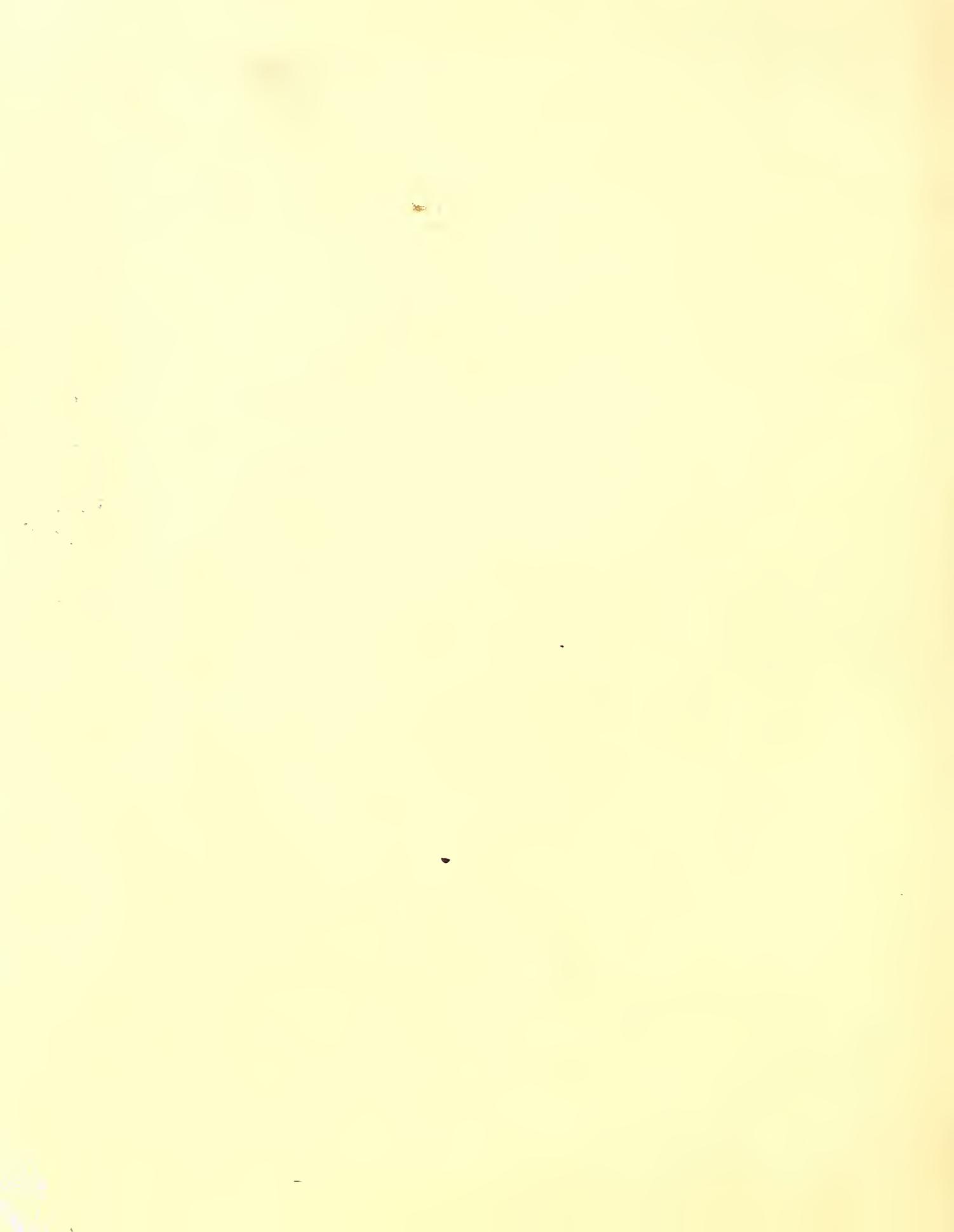


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**CITRUS FRUIT APPEARANCE, WEIGHT LOSS, AND
INTERNAL CONDITION INFERENCES
FOR MECHANICAL HARVESTING**

ARS-W-5
April 1973

WESTERN REGION

ACKNOWLEDGMENTS

The work reported herein was conducted by the authors while the senior author was on sabbatical assignment with the Harvesting and Farm Processing Research Branch, Agricultural Research Service, at the University of California, Riverside (UCR), from September 1967 to August 1968.

The authors wish to acknowledge the excellent cooperation and assistance received from J. W. Eckert, plant pathologist (Decay Studies); I. L. Eaks, plant physiologist (Respiration Rate and Internal Atmosphere Studies); C. W. Cog-

gins, plant physiologist; (Histological Study); Bruce Kramer and Alice Ricker, laboratory assistants; the Agricultural Engineering Department personnel at the University of California, Riverside; and Rodney Lehman, chemist, and Hugh Fitzpatrick, plant pathologist of the FMC Corporation, Riverside, Calif.

The purpose of this study was to evaluate several surface treatments which might reduce the postharvest deterioration of mechanically harvested citrus.

CONTENTS

	Page
Decay	1
Deterioration of rind surface appearance	2
Exploratory tests	2
Weight loss tests	4
Internal atmosphere	9
Respiration rate	10
Histological study of rind surface	12
Discussion and conclusions	13

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CITRUS FRUIT APPEARANCE, WEIGHT LOSS, AND INTERNAL CONDITION INFERENCES FOR MECHANICAL HARVESTING

W. F. Millier and G. K. Brown¹

Mechanical harvesting systems are likely to injure the surface of citrus fruit by contact between the fruit and the tree before and after fruit detachment. By increasing the number of

openings in the fruit surface, such injuries increase the amount of decay and detract from the appearance of the fruit.^{2 3}

DECAY

We conducted limited decay studies of mechanically harvested oranges, lemons, and grapefruit. All fruits were washed, brushed, and dried (at the University of California (UCR) Fawcett Laboratory pilot plant), then dipped in a 35-gallon solution of 0.05 percent triton X-100 (wetting agent) and water containing a suspension of 0.88 grams *Penicillium digitatum* spores. The fruits were then stored at 68° F. and 90+ percent relative humidity (R.H.) for 12 to 20 hours. All treatments were then dipped in a 0.05-percent triton X-100 and water solution with or without fungicide, dried, and packed in cartons. Decay counts were made after 10 to 12 days' storage at 68° F. and +90-percent R.H.

The results shown in table 1 can be considered as a maximum decay condition because the fruit was inoculated with *Penicillium digitatum* spores. The increased incidence of decay is evident as is the possibility of decay control with both of the fungicides.

To determine if a fumigation treatment would provide better decay control than a dip treatment, a test using injured fruit was included in other fumigation work being conducted with 2-Aminobutane. The fumigation treatment resulted in 100-percent control of decay. However, all injuries opened up, due to dehydration during fumigation, making the surface appearance very objectionable.

²/Grierson, W. Effect of mechanical harvesting on suitability of oranges and grapefruit for packinghouse and cannery use. Fla. State Hort. Soc. Proc. 81: 53-61. 1968.

³/Schertz, C. E., and Brown, G. K. Basic considerations in mechanizing citrus harvest. Amer. Soc. Agr. Engin. Trans. 11(3): 343-346. 1968.

TABLE 1.—*Decay of mechanically harvested citrus fruit after 10 to 12 days storage at 68° F. and high relative humidity*

Method of harvest	Treatment	Decayed fruit			
		Valencia oranges	Eureka lemons	Marsh grapefruit	White grapefruit
		Percent	Percent	Percent	Percent
Handpicked	Inoculated-no fungicide	—	6.6	11.5	
Mechanical ¹	— — — do — — —	10.4	42.7	26.9	
Mechanical	Inoculated fungicide ²	6.2	9.3	.5	
Mechanical	Inoculated fungicide ³	8.3	4.2	—	

¹Valencia oranges were harvested with the roll harvester; lemons and grapefruit, with a limb shaker.

²2-percent 2-Aminobutane, 30-second dip.

³2,500 p.p.m. thiabendazole, 30-second dip.

DETERIORATION OF RIND SURFACE APPEARANCE

Immediately after mechanical harvest, very careful inspection of the rind surface is necessary to detect injury other than that caused by removal of tissue and exposure of the albedo. After a few hours in a drying atmosphere, shrinkage of the rind tissue in and around the injury opens the scratch, cut, or puncture, making each injury very obvious.

Shrinkage of the rind tissue is more pronounced in the injured area because moisture loss is more rapid. As moisture is lost, the cells become smaller, resulting in movement of tissue laterally and towards the fruit center, leaving an open, sunken scar on the rind surface. If this scarring is to be prevented, the moisture loss in the injury must be no greater than in other areas of the rind tissue.

Exploratory Tests

We conducted a series of initial tests to determine the treatments and conditions that should be included in a study of the weight loss of Washington naval oranges.

To determine the effect of relatively severe surface injury on weight loss, some fruits were artificially injured. To obtain uniformity of injury, a scratching tool was constructed (fig. 1). The length of the scratch was controlled by a 3/32- by 1-inch slot cut in a template made from 0.005-inch shim stock. The template also protected the rind from possible injury due to the sole of the tool sliding across the fruit surface.

Two depths of scratch were selected: (1) shallow (0.025 inch), into but not through the flavedo; and (2) deep (0.075 inch), through the flavedo and into the albedo. The flavedo is the outer, more dense region of cells of the rind approximately 1 millimeter thick. The albedo is the white tissue below the flavedo.

Each treatment consisted of four replications of five fruits each. All fruit were of the same size and were harvested January 24. Washing consisted of soaking for 3 minutes in a 0.5-percent detergent solution followed by brushing with detergent solution 15 to 30 seconds and rinsing with clean water. The fruits were then conveyed through a washer and air dryer.

For decay control, all of the treatments were

dipped for 30 seconds in a 1-percent 2-Aminobutane phosphate solution after the button was removed and the injuries inflicted. Some treatments were waxed before button removal or injury, while other treatments were waxed after button removal or injury. Waxing was accomplished by dipping for 30 seconds in FMC 7059, 15-percent total solids, wax emulsion. This wax contained polyethylene and was selected because it dried rapidly and did not leave a tacky surface. Dip waxing created a thick wax layer over the entire fruit and was easily replicated. After waxing, each fruit was placed on a wire rack to dry.

The fruits were stored at near constant temperature and R.H. Higher temperature and lower R.H. than recommended for naval orange storage⁴ were chosen to simulate unrefrigerated storage conditions which would accelerate dehydration. Treatment replications were randomly located on holding trays to eliminate the effects of air velocity, temperature, and R.H. variations in the room. The holding trays were constructed such that each fruit was supported on a plastic ring to allow free air passage around the entire fruit. The total elapsed time from fruit harvest to the first weighing was 7 hours.

To determine rate of weight loss, weighings were made daily for the first 9 days, then every 3 to 5 days for the remainder of the test. Each weighing interval was taken as a drying period, and a mean rate of weight loss, given in grams per 100-gram hours, was determined for each period. The mean of the rates of weight loss for the four replications was taken as the rate of weight loss for the treatment during that period and was assumed to be valid only for the midpoint in the period.

The rate of weight loss versus time (fig. 2) was a power function. Figure 3 shows the fit of a straight line to a logarithmic plot of the data for four treatments.

Regression equations in the form:

$$\text{Log}_e y = \text{Log}_e C + n \text{ Log}_e x$$

where:

y = rate of weight loss, in grams per 100-gram hours

C = constant, y intercept when $x = 1$

⁴Lutz, J. M., and Hardenburg, R. E. The commercial storage of fruits, vegetables, and florist and nursery stocks. U.S. Dept. Agr. Handbook 66, 94 pp. 1968.

n = slope

x = hours after treatment

were obtained by the ordinary least squares method for each of the treatments. The coefficients, C , and exponents, n , also apply to the arithmetical form $y=Cx^n$. The total loss in weight per 100 grams of fruit for any given period is the area under the curve obtained by integration of the function $y=Cx^n$ for that particular treatment. The percent loss in weight during the period, based on the weight of the fruit at the beginning of the period, is:

$$\text{Percent weight loss} = \frac{A}{100 + A} \times 100$$

where:

A = the area under the curve, in grams per 100 grams

We compared the calculated losses with

the actual losses and found a very close comparison for some treatments but not all. A close comparison was associated with a high degree of controlled treatment (injury + waxing) whereas a poor comparison was associated with a low degree of controlled treatment (washed only).

Ambient conditions of temperature and R.H. varied by ± 3 percent during the test. Also, air velocities around the fruit probably were not constant. Therefore, the actual weight loss recorded is not that which would result with constant conditions. We do not know which of the two losses, calculated or actual, would be more correct for a constant ambient condition.

These tests indicated that such injury depth (artificially inflicted), washing and waxing the surface, the waxing material and method, and fluctuations in ambient conditions, all had an effect on the rate of weight loss. If the fruits

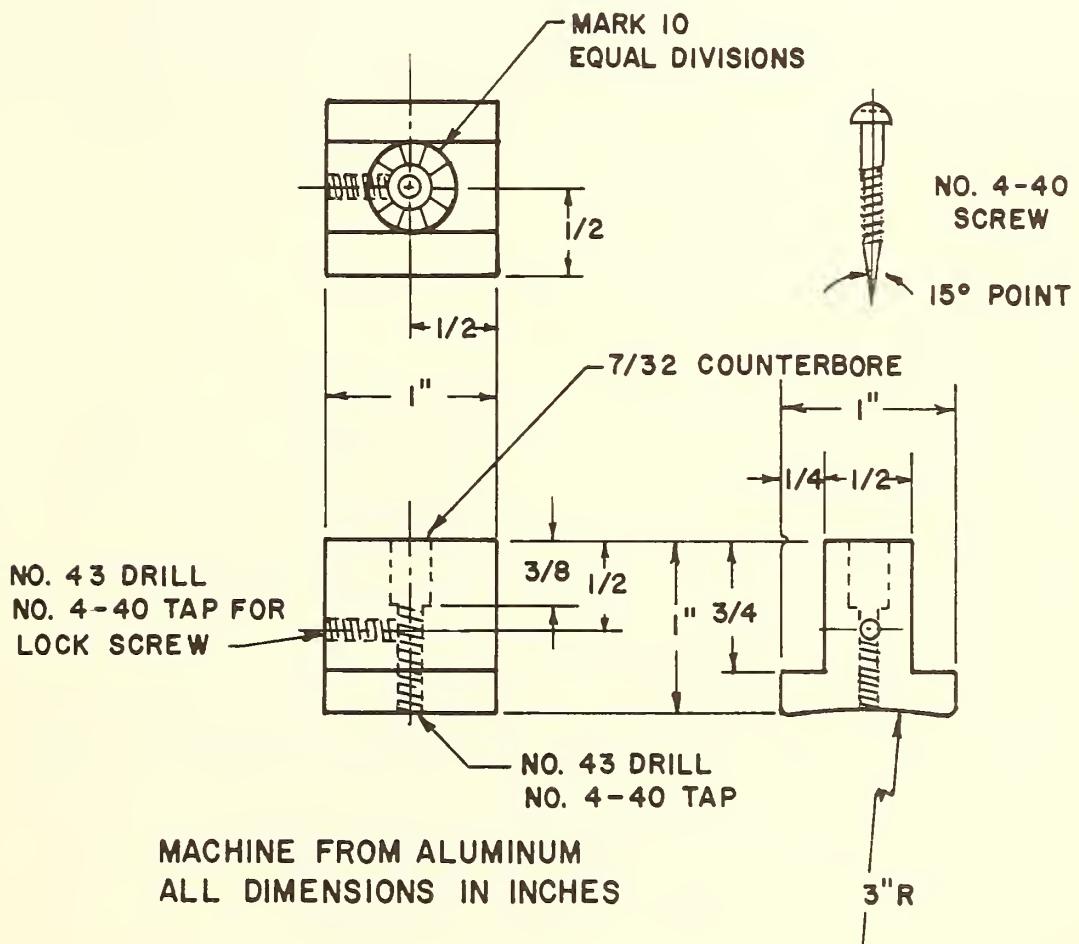


Figure 1.—Details of scratching tool.

were held in closed polyethylene bags, they rapidly created a high humidity environment which prevented shrinkage of the rind tissue around an injury.

Weight Loss Tests

A final series of tests were set up to include R.H.'s at 85 to 90 percent, 60 to 65 percent, and 32 to 37 percent. Temperature was again 75° F. Rooms used at the Fawcett Laboratory were equipped with a temperature and R.H. control. However, the control could only add moisture to the air. Moisture was removed by the refrigeration unit when it operated to reduce temperature. This caused cycling of the humidity control system and resulted in R.H. fluctuations of from 3 to 5 percent.

Fruits were harvested March 28 for the high R.H. room, March 29 for the medium R.H. room, and April 2 for the low R.H. room. All fruits were prepared in the same manner as previously described except that a 2-percent 2-Aminobutane solution was used for decay control. Treatments used in these tests are given in table 2.

The weight loss data were analyzed as previously described and the results are presented in a similar manner. Example graphs (figs. 4 to 7) of the rate of weight loss versus time were prepared from solutions of the regression equations and do not show the experimental points. The treatments were selected to show the effects of (1) washing and brushing and (2) injury on the rate of weight loss of waxed and unwaxed fruit stored at the three different R.H.'s.

The coefficients and exponents for the general equation $y = Cx^n$ for the treatments in the weight loss tests are tabulated in table 2.

The actual percent weight loss and the weight loss determined by the regression equation can be directly compared in table 2. The higher weight loss caused by the washing and brushing operation exists at all humidity levels in both waxed and unwaxed fruit. The effect is greater when fruits are unwaxed and stored at the low R.H.

Removal of the button caused a change in weight loss varying from about 1 percent greater loss in unwaxed fruit to less than $\frac{1}{2}$ percent lower loss in waxed fruit. Comparing the losses

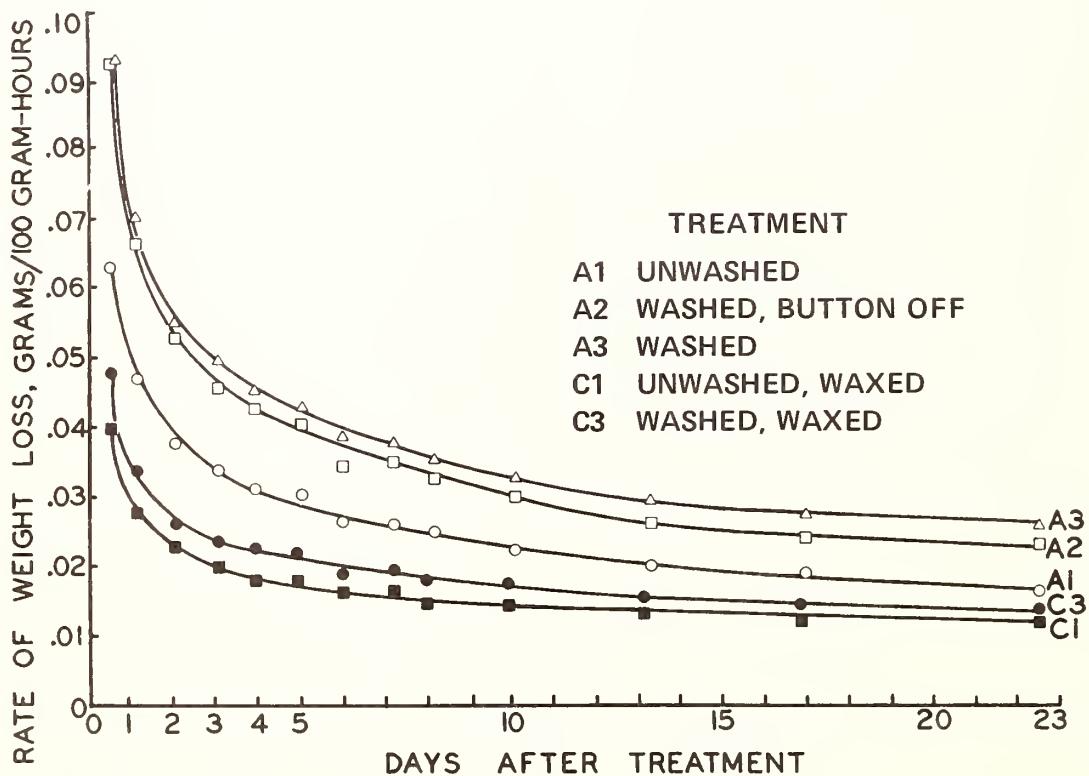


Figure 2.—The effect of washing and waxing on the rate of weight loss of uninjured Washington navel oranges, held at 75° F. and 35 percent R.H., exploratory test.

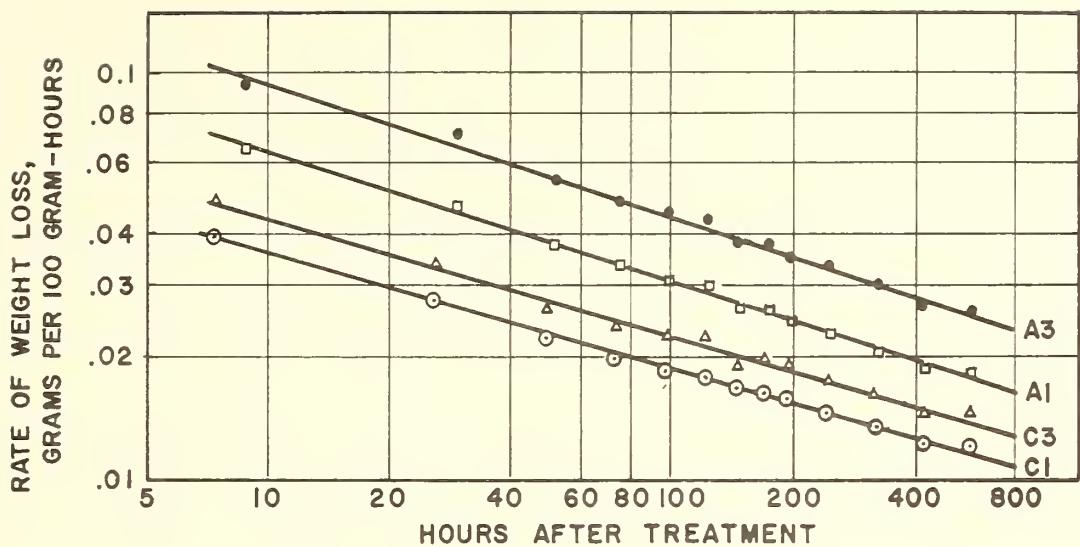


Figure 3.—Logarithmic plot of mean rate of weight loss versus time, for treatments A1, A3, C1, and C3; 75° F. and 35 percent R.H.

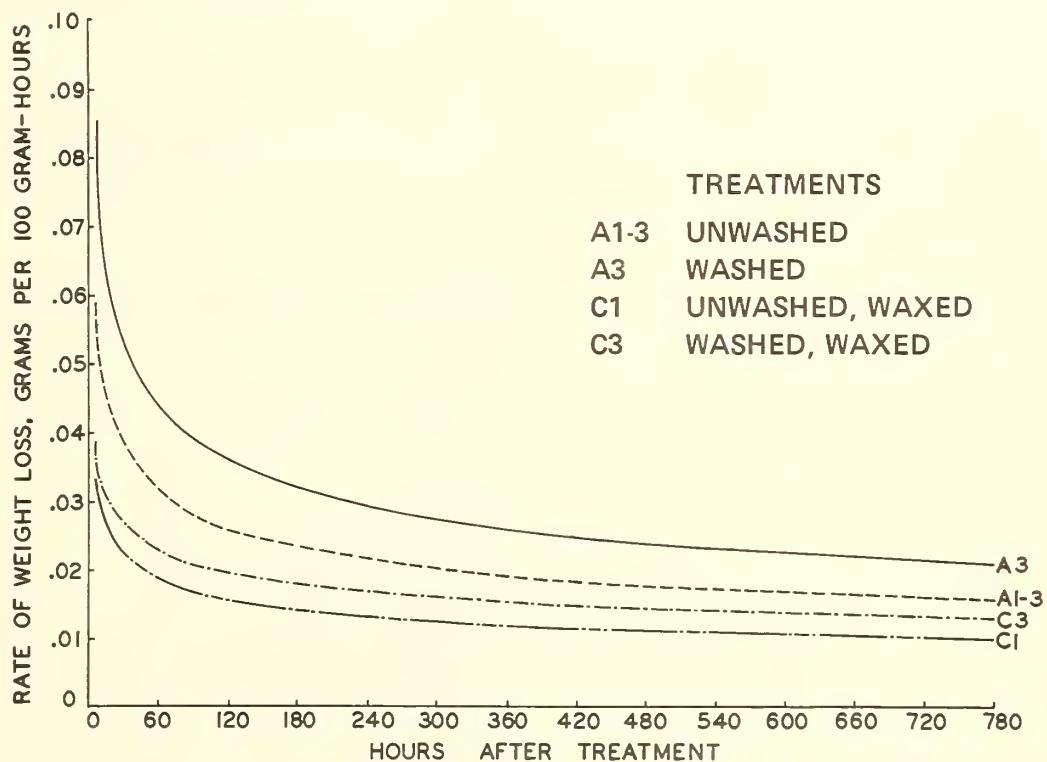


Figure 4.—The effect of washing and waxing on the rate of weight loss versus time of uninjured Washington navel oranges, 75° F. and 34 percent R.H.

TABLE 2.—Summary of weight loss and internal atmosphere, Washington naval oranges, March 1968

Fruit treatment		Storage conditions		Weight loss coefficients ¹		Weight loss (30-day storage)		Internal atmosphere (35- to 38-day storage)			
Code	Description	Temperature	Percent R. H.	C	n	Actual percent	Calculated percent	CO ₂	SE ⁵	Percent O ₂	SE ⁵
UNWAXED											
A1-2	Unwashed Button off	75	34	0.1102	—	—0.2925	15.5	14.1	6.2	0.5	14.0
		74	63	.0815	—	.2816	11.8	11.4	5.9	.7	15.4
		73	91	.0377	—	.2639	6.1	6.1	5.9	.6	15.2
A1-3	Unwashed Button on	75	34	.0958	—	.2711	14.4	13.7	9.8	.8	8.3
		74	63	.0758	—	.2910	10.5	10.2	6.3	.9	14.7
		73	91	.0345	—	.2818	5.1	5.1	4.3	.7	17.0
A1-4	Unwashed 0.025-inch scratch ²	75	34	.1288	—	.2718	18.3	17.6	—	—	—
		74	63	.0994	—	.2839	13.6	13.4	—	—	—
		73	91	.0358	—	.2595	5.9	5.9	—	—	—
A1-5	Unwashed 0.075-inch scratch ³	75	34	.1236	—	.2504	19.8	18.6	—	—	—
		74	63	.0958	—	.2658	14.8	14.1	—	—	—
		73	91	.0341	—	.2190	7.1	6.9	—	—	—
A2	Washed Button off	75	34	—	—	—	—	—	—	—	—
		74	63	.1236	—	.3178	14.1	13.9	6.3	.7	14.4
		73	91	.0481	—	.3001	6.9	6.4	4.9	.4	16.0
A3	Washed Button on	75	34	.1433	—	.2888	18.9	17.8	13.5	.8	5.2
		74	63	.1085	—	.3023	13.9	13.3	9.1	.8	10.4
		73	91	.0489	—	.3134	6.2	6.1	5.3	3	15.1
A4	Washed 0.025-inch scratch ²	75	34	.1539	—	.2675	22.2	20.7	—	—	—
		74	63	.1340	—	.2841	18.4	17.2	—	—	—
		73	91	.0514	—	.2697	8.0	7.9	—	—	—
A5	Washed 0.075-inch scratch ³	75	34	.1566	—	.2524	24.2	22.3	—	—	—
		74	63	.1433	—	.2879	19.1	17.9	—	—	—
		73	91	.0496	—	.2471	8.2	8.1	—	—	—
INJURED AFTER WAXING⁴											
B2	Washed Button off	75	34	—	—	—	—	—	—	—	—
		74	63	.0672	—	.3218	8.0	7.9	5.6	.4	15.3
		73	91	.0271	—	.3042	3.7	3.7	5.1	.4	15.3
B4	Washed 0.025-inch scratch ²	75	34	—	—	—	—	—	—	—	—
		74	63	.0709	—	.2576	11.6	11.2	12.4	1.4	7.5
		73	91	.0287	—	.2722	4.5	4.5	7.2	.5	11.0
B5	Washed 0.075-inch scratch ³	74	63	—	—	—	—	—	—	—	—
		73	91	.0706	—	.2344	13.0	12.4	5.4	.5	16.0
				.0259	—	.2263	5.2	5.2	4.5	.4	16.6

INJURED BEFORE WAXING ⁴		34	.0517	—	.2459	8.9	8.9	8.4	.9	11.8	1.0
C1	Unwashed	75	.0412	—	.2507	7.3	7.1	6.7	.7	12.1	1.7
	Button on	74	.0213	—	.2974	3.0	3.0	7.0	.6	12.8	.9
C2	Washed	75	34	—	—	—	—	—	—	—	—
	Button off	74	.0656	—	.3240	8.0	7.7	8.2	.5	10.7	.8
		73	.0293	—	.3307	3.4	3.5	8.5	.7	9.5	1.3
C3	Washed	75	34	.0577	—	.2230	11.3	11.0	13.3	1.1	5.2
	Button on	74	.0458	—	.2520	7.8	7.7	9.0	.8	8.8	1.1
		73	.0238	—	.2697	3.8	3.8	9.1	.6	7.3	.8
C4	Washed	75	34	.0805	—	.2258	15.0	14.5	—	—	—
	0.025-inch scratch ²	74	.0642	—	.2576	11.3	10.3	11.9	1.2	6.9	1.0
		73	.0277	—	.2642	4.6	4.5	9.3	.7	5.9	.9
C5	Washed	75	34	.0866	—	.2236	16.5	15.6	—	—	—
	0.075-inch scratch ³	74	.0678	—	.2442	12.4	11.5	10.1	.6	9.0	.6
		73	.0250	—	.2446	4.5	4.6	7.4	.4	11.3	.9

¹ For the equation $y = Cx^n$.

² Two 1-inch long by 0.025-inch deep scratches per fruit.

³ Two 1-inch long by 0.075-inch deep scratches per fruit.

⁴ 30-second dip in FMC 7059, 15 percent total solids wax emulsion.

⁵ Standard error of the mean.

CONTINUATION OF TABLE 1
SUSCEPTIBILITY OF MELONS

TABLE 2

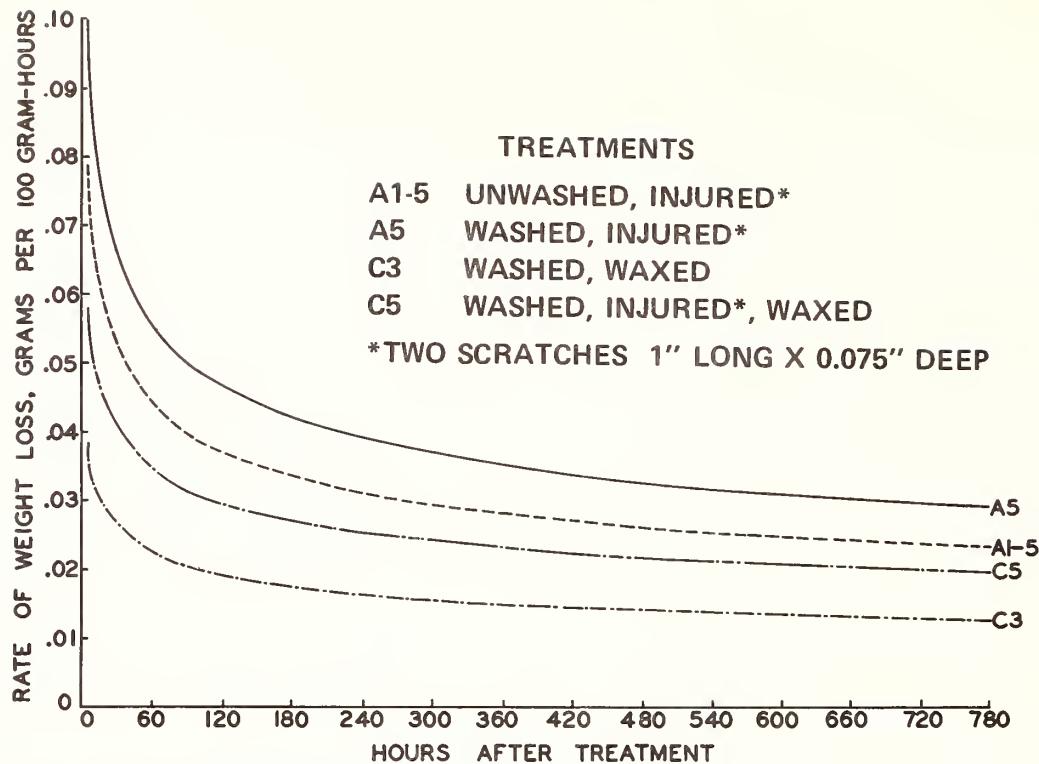


Figure 5.—The effect of washing and waxing on the rate of weight loss versus time of injured Washington navel oranges, 75° F. and 34 percent R.H.

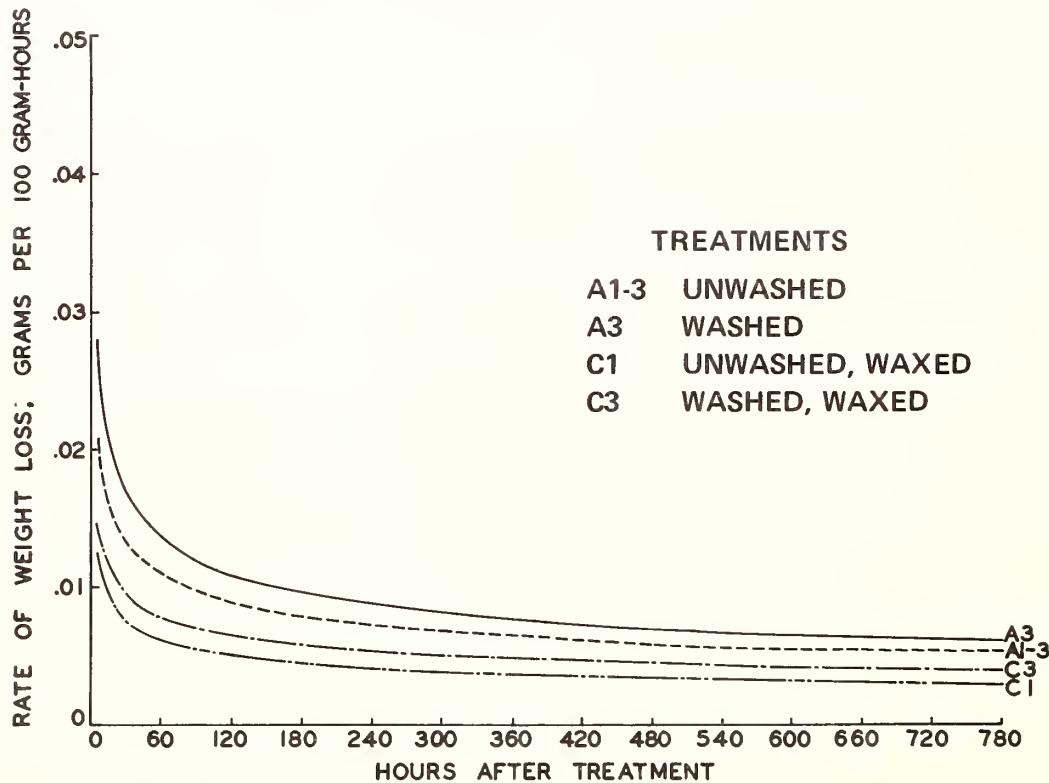


Figure 6.—The effect of washing and waxing on the rate of weight loss versus time of uninjured Washington navel oranges, 73° F. and 91 percent R.H.

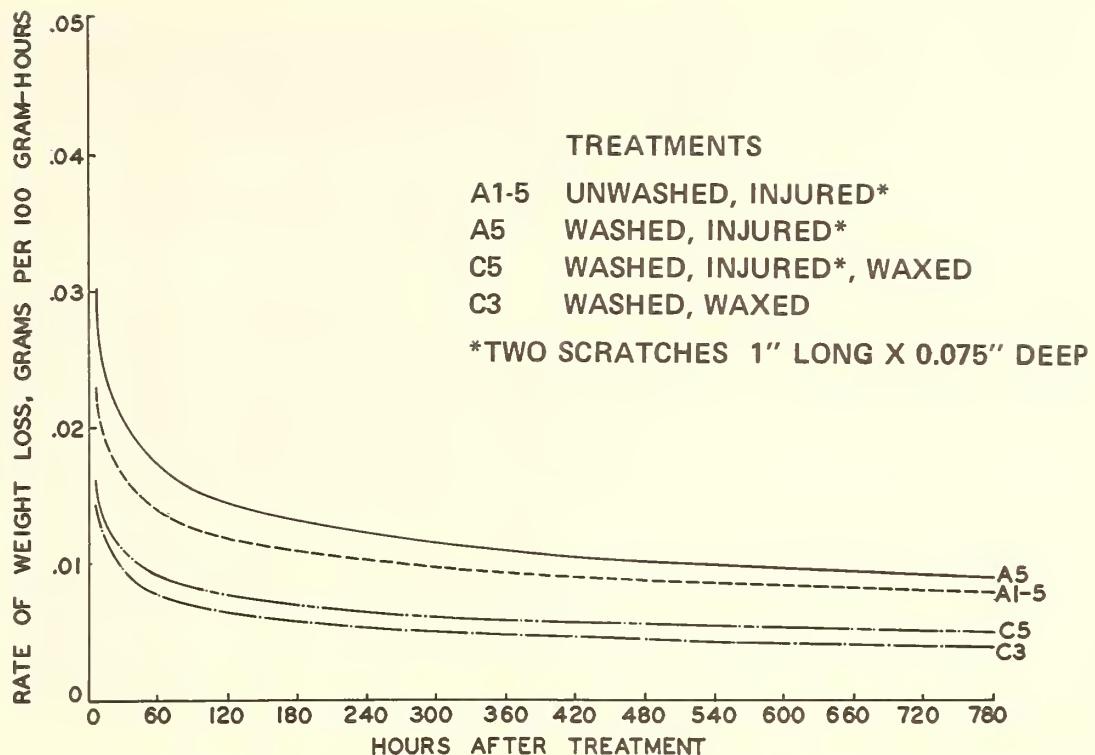


Figure 7.—The effect of washing and waxing on the rate of weight loss versus time of injured Washington navel oranges, 73° F. and 91 percent R.H.

of the washed waxed button off (B2) treatment with the washed button on waxed treatment (C3), the weight loss due to button removal is 0.2 percent during a 30-day period. When similar comparisons were made, the calculated losses in weight due to two scratches, 1 by 0.025 inch (B4 minus C3), are 3.5 percent at 63 percent R.H. and 0.7 percent at 91 percent R.H. Calculated losses in weight due to the two scratches, 1 x

0.075 inch, are 4.7 percent at 63 percent R.H. and 1.4 percent at 91 percent R.H.

The final appearance of washed scratched waxed fruit (C4, C5) for the 91 percent R.H. condition is shown in figure 8. Dehydration around these relatively severe scratches is excessive for fresh market fruit. However, their appearance is better than for fruit scratched but not waxed (A1-4, A1-5).

INTERNAL ATMOSPHERE

Citrus fruits continue to respire after harvest. O_2 is necessary for respiration and CO_2 is one of the byproducts. The levels of O_2 and CO_2 in the internal atmosphere of the fruit are indicators of the ability of the fruit to take in O_2 and dispose of CO_2 . The levels are also an indirect measure of the ability of O_2 and CO_2 to move through the rind and whatever surface wax may be present. O_2 concentration below 5 percent usually causes anaerobic respiration,⁵ resulting in internal breakdown of the fruit. At

the time of harvest, the O_2 level is high, near 20 percent, and the CO_2 level is low, in most cases less than 4 percent.

The internal atmosphere of most treatments was measured at the end of the test. One-cubic-centimeter samples of the internal atmosphere were obtained by inserting a hypodermic needle through the button abscission into the internal cavity of the fruit. The fruit was then immersed in water and the sample withdrawn into the syringe. Immersion prevented any leakage of ambient air into the syringe during sampling. The sample was then injected into a gas chromatograph calibrated for O_2 and CO_2 analysis.

⁵/ Webber, J. R. Post-harvest life of citrus fruit. Calif. Citrograph 42:403. 1967.

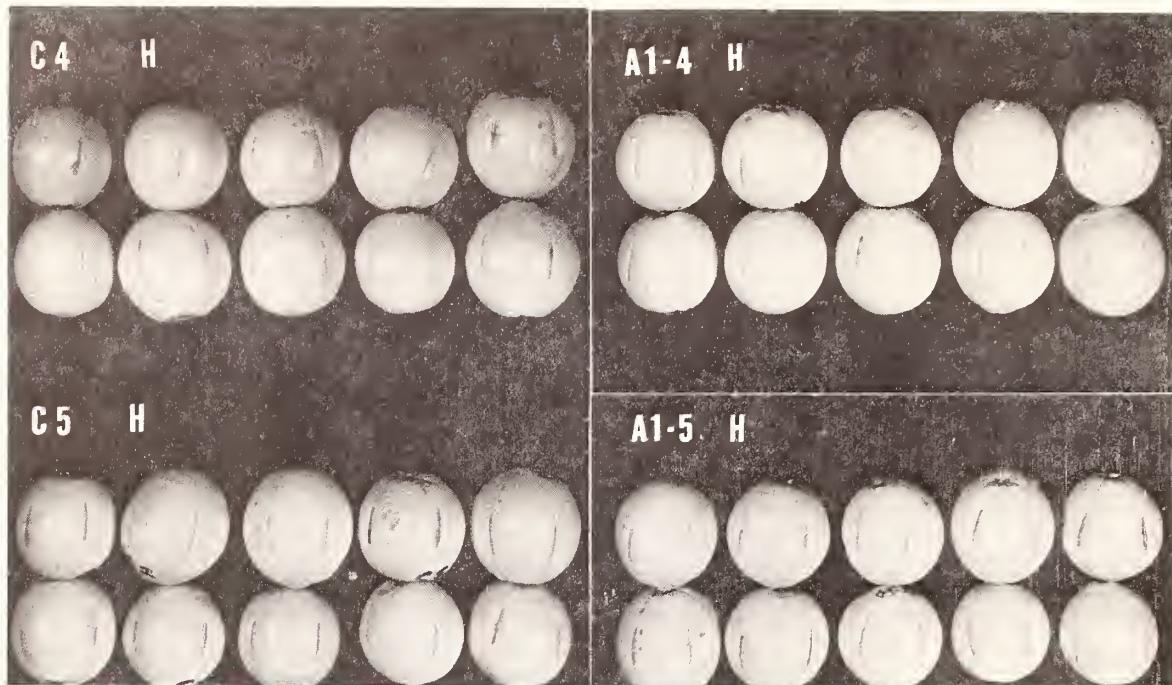


Figure 8.—Final appearance of injured fruit with 0.025- and 0.075-inch scratches, waxed after injury (left) and unwaxed (right), held at 73° F. and 91 percent R.H.

The internal atmosphere for treatments in the weight loss tests are summarized in table 2. After 35 to 38 days storage there were changes in the internal atmosphere due to the treatments. Treatment A1, unwashed unwaxed, represents what happens to untreated fruit and therefore serves as the control. In the group of unwaxed treatments, A3 shows an increase in CO_2 and a decrease in O_2 with respect to A1-3. This change was caused by the washing and brushing operation. Treatment A2 was also washed and brushed in the same manner as A3, but the button was removed after washing. Removal of the button counteracted the effect of washing because there was no large increase in CO_2 or decrease in O_2 in the internal atmosphere. The additional gaseous exchange apparently took place through the button abscission.

A similar effect is noted if treatment C3 is compared to B2. Again the only difference in these treatments is that after waxing the button was removed from B2. B2 has less CO_2 and more O_2 in its internal atmosphere than C3. The detrimental effect of washing is also demonstrated in the "C" treatments by comparing C1 and C3. C1 was not washed and has less CO_2 and more O_2 than C3. Scratching the rind surface provides a path for gaseous exchange in the respiration process.

The effect of R.H. can be observed in most of the treatments. Increasing the R.H. caused a reduction in CO_2 buildup and an increase in O_2 level in the internal atmosphere. This suggests that gaseous exchange in the respiration process is reduced by dehydration or shrinkage of the fruit.

RESPIRATION RATE

The levels of CO_2 and O_2 in the internal atmosphere of the fruit differ with injury depth. The fruit with the deep injury had lower CO_2 and higher O_2 levels. In an attempt to explain this result, a test was conducted to determine the effect of injury depth on the production of CO_2 . Twelve unwashed navel oranges were seal-

ed individually in glass jars with a CO_2 -free airflow (high R.H., 68° F.) of 8 liters per hour through each jar. The exhaust air was analyzed to determine the CO_2 production of each fruit⁶

⁶/ Eaks, I. L. Techniques to evaluate injuries to citrus fruit from handling practices. Amer. Soc. Hort. Sci. Proc. 78: 190-196. 1961.

for 24 hours. This established a preinjury respiration rate. Eight fruits were removed from the jars and injured — four with two scratches 1 inch long by 0.025 inch deep and four with two scratches 1 inch long by 0.075 inch deep. As a decay control measure, the scratching tool was dipped in a 2-percent 2-Aminobutane solution before each scratch. The fruit were returned immediately to the jar and CO₂ production was determined for 6 consecutive days. CO₂ production, expressed as percentage of preinjury production of CO₂ is shown in figure 9. When the fruits were returned to the jars, there was an immediate reduction in CO₂ production. This was attributed to the use of 2-Aminobutane on the scratching tool. The shallow scratches caused an increase in CO₂ production of approximately 10 percent, whereas the deep scratches caused an increase of about 30 percent, both peaking 12 to 24 hours after injury. CO₂ production of fruit with deep scratches remained about 20 percent higher than the check fruit, whereas that of fruit with shallow scratches was near the check.

At the end of the test period, the levels of CO₂ and O₂ in the internal atmosphere were measured and found to be the same for all

treatments. Thus, the higher CO₂ production for unwashed unwaxed fruit with deep scratches was not reflected in a higher level of CO₂ in the internal atmosphere.

A probable explanation for the lower CO₂ and higher O₂ levels in fruit with deep injuries is that the deep injuries opened up the albedo tissue, allowing a freer gaseous exchange between the inside and outside of the fruit. The greater respiration rate of the fruit with the deep injuries would have caused high CO₂ and low O₂ in the internal atmosphere if the deep scratches did not provide for a freer gaseous exchange.

A similar test, to determine the effect of washing and waxing on the external production of CO₂, was conducted with Valencia oranges because the late season navel oranges were in poor condition. In this test four treatments were included: washed, unwashed, washed waxed, and unwashed waxed. A respiration rate for each fruit was established before treatment. The wash treatment was the same as previously described, and all fruits were dipped for 15 seconds in a 2-percent 2-Aminobutane solution for decay control. The wax coating was applied by dipping for



Figure 9.—External carbon dioxide production of unwashed Washington navel oranges with 2 depths of rind injuries. CO₂ production before injury was taken at 100 percent for all groups. The reduced CO₂ production immediately after treatment is attributed to the 2-Aminobutane dip for decay control.

15 seconds in FMC 707, 20 percent total solids wax emulsion.

The washing and brushing operation caused an initial increase in external CO_2 production in both the waxed and unwaxed fruit (fig. 10),

but this effect disappeared after 3 days. The wax coating decreased the external CO_2 production in both washed and unwashed fruit. This effect still existed at the termination of the test (approximately 11 days after treatment).

HISTOLOGICAL STUDY OF RIND SURFACE

The cleaning operation may cause changes in the surface that affect gaseous exchange through the rind. To determine if changes occurred, slides of Valencia orange rind were prepared that had treatments similar to those in the weight loss studies. Waxing was accomplished by dipping fruit in FMC 707, 20 percent total solids wax emulsion that had been colored yellow. Preparation of the rind sections for microscopic study had to be done in a manner that would not change the rind surface. Staining materials using solvents that would remove any of the surface waxes or other material could not be used. Relatively thick tissue sections (25 to 30 microns) were cut on a cryostat and mounted in Karo syrup. These were stained with a water solution of ruthenium red, which does not stain waxy material, and then photographed. Although definite conclusions cannot be drawn from such

a limited study, the following theory is presented as a possible answer to the question; What does washing and brushing do to the rind surface?

The purpose of the washing and brushing operation is to remove field dirt from the surface. The dirt appears to be embedded in the natural surface wax. Brushing alone will not clean the surface. Soaking in a detergent solution plus brushing will clean the surface, but some of the natural wax is removed by the wiping action of the brush fibers (fig. 11). The wiping action could move waxy material into the stomal openings or force the stomal lips downward causing material to be trapped thus plugging the stomal opening.

Removal of the natural wax from the rind surface could explain why there is an increase in weight loss. Moisture loss through the cuticle

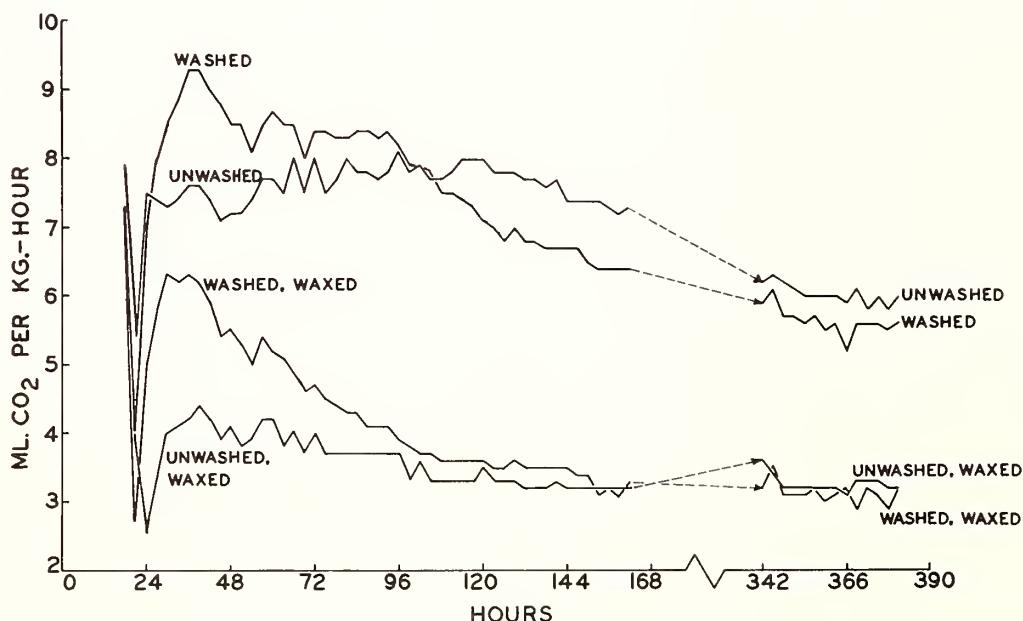


Figure 10.—External carbon dioxide production of washed, unwashed, washed waxed, and unwashed waxed Valencia oranges. Pretreatment rates were: unwashed, 7.9; washed, 7.4; unwashed waxed, 7.5; washed waxed, 7.4 ml. CO_2 per kilogram of fruit per hour. The reduced CO_2 production immediately after treatment is attributed to the 2-Aminobutane dip for decay control.

would be greater with the natural surface wax removed. The wiping action and many small impacts could account for the higher respiration rate. Since the stomata are important in gaseous exchange, their plugging could be the reason for the buildup of CO_2 in the internal atmosphere of washed fruit.

The projection of the stomal lips above the general level of the rind surface appears to be

the reason why wax coatings, if not too thick, do not completely seal the fruit surface. When fruits are dipped and removed from a wax emulsion, the excess liquid runs off. The interaction of the emulsion's surface tension and the adhesion of the emulsion to the unwashed stoma is such that the coating flows around the stomal lips and does not cover the stomal opening (figs. 12 and 13).



Figure 11.—Washed unwaxed Valencia rind cross section. Some of the natural surface wax has been removed.



Figure 12.—Unwashed waxed Valencia rind cross section. Two stomata are visible, one in the center and one on the right. Note that the wax does not extend over the top of the stomal lips. The wax surface is approximately flush with the top of each stoma.



Figure 13.—Washed waxed Valencia rind cross section. The stoma just left of center is completely surrounded with wax. There may be a small covering of wax over the stomal opening.

DISCUSSION AND CONCLUSIONS

Present mechanical harvest methods for citrus fruit can cause rind injuries varying in severity from scratches that remove the natural surface wax to cuts and punctures extending through the rind and into the flesh of the fruit. Such injuries increase: the rate of weight loss, the rate of respiration, and the incidence of decay.

The increase of weight loss due to dehydration of the tissue in and around the rind injury site causes the development of a scar that de-

tracts from the appearance of the fruit. Such surface scarring is not presently acceptable for fresh market citrus. Dehydration can be reduced by maintaining high water vapor pressures around the fruit after injury has occurred and providing a protective coating over the injury.

Fruit held in vapor-tight containers will rapidly develop a high R.H. that will slow dehydration and prevent scar development from taking place before washing and waxing. This high humidity environment would favor the

germination of decay spores and might require the application of a fungistat immediately following harvest. Placing mechanically harvested citrus in vapor-tight containers during harvest would probably prevent scar development before washing and waxing.

After packing for market, it would be more difficult to control the humidity level around the fruit. An ideal surface coating that would keep dehydration of the rind very low so that the shrinkage of the injury would be the same as that of uninjured rind tissue would be necessary to prevent scar development. Such a coating should be nearly impervious to the passage of water vapor but must allow passage of O_2 and CO_2 to and from the fruit.

The weight loss test described can be used to evaluate various fruit waxes and waxing methods. It may also be useful as a measure of fruit injury. The rate of weight loss can be represented by the equation $y=Cx^n$.

It was found that the washing and brushing operation, as may be practiced in many packing-houses to clean the fruit, had an adverse effect on navel oranges. It caused an increase in the rate of weight loss, and respiration, a decrease in O_2 , and an increase in the CO_2 content of the internal atmosphere of the fruit. It was also observed that a heavy wax coating could be applied to the surface of unwashed navel oranges without causing suffocation, whereas the same coating applied to washed and brushed navel

oranges would cause internal breakdown of the fruit.

A microscopic study of the rind surface of Valencia oranges showed that: the stomal openings are elevated with respect to the general rind surface, washing and brushing removes some of the natural wax from the rind surface and tends to push down or compress the stomal openings, and a wax emulsion will not seal the stomal openings if they protrude above the wax layer.

Our results indicate that a wax can be applied to control dehydration of the rind, without adverse effects on internal quality, if the stomal openings are not covered. There is less risk that the stomal openings will be covered if the fruit is not washed and brushed. The characteristics of the waxing material and its method of application will affect its ability to form around but not cover the stomal openings.

We have evidence that the postharvest deterioration of mechanically harvested citrus can be controlled. Present practices must be changed to provide better decay control treatments, minimum dehydration, and a method of cleaning the fruit that does not harm the rind surface. These changes, coupled with the development of waxing materials and application methods to control cuticular dehydration without interference with the function of the stomata, could lead to the acceptance of a significant amount of mechanically harvested citrus on the fresh market.



